CLAIMS

1. A method for measuring the operating state of synchronous motor by using composite power angle meter, comprising the steps of:

a. Obtaining various electric signals and digital signals of the synchronous motor and its system;

b. Converting the electric signals into digital signals by an internal data collection part of the composite power angle meter, and inputting all the obtained digital signals to a host computer;

c. Inputting related parameters or commands to the host computer by keyboard and mouse;

d. Program-processing the related data by the computer, calculating the data by a computing program to obtain the coordinates of relevant points and related data, and inputting the results to a displaying program;

e. Using the coordinates of main points and the calculation results to depict an electric model graph, a mechanical model graph and a motor-end composite magnetic leakage graph of the synchronous motor through the displaying program process by the computer, displaying on a display a dynamic composite power angle graph and the motor-end composite magnetic leakage graph which vary with the motor's parameters, and realizing an alarm function.

2. The method for measuring the operating state of synchronous motor by using composite power angle meter according to Claim 1, wherein the displaying program process comprises establishing coordinates of images and imaging; and the computing program process comprises determining parameters, calculating parameters, determining the value of the direct-axis synchronous reactance of the synchronous motor and alarming.

3. The method for measuring the operating state of synchronous motor by using composite power angle meter according to Claim 2, wherein the displaying program process and computing program process comprise the following steps for a non-salient-pole synchronous motor:

The displaying program process including:

(1) Establishing image coordinates of composite power angle graph, electric power angle vector graph, motor mechanical model graph, motor mechanical model schematic graph, synchronous composite power angle graph and motor end composite magnetic

leakage graph of the non-salient-pole synchronous motor:

Composite power angle graph: $A_{10}(a, b)$, $C_{10}(e, 0)$, $D_{10}(0, 0)$, $G_{10}(a, 0)$;

Electric power angle vector graph: $A_{11}(a, b)$, $C_{11}(e, 0)$, $D_{11}(0, 0)$;

Motor mechanical model graph: $A_{12}(\frac{a}{2}, \frac{b}{2})$, $C_{12}(\frac{e}{2}, 0)$, $D_{12}(0, 0)$, $A_{13}(-\frac{a}{2}, -\frac{b}{2})$, $C_{13}(-\frac{e}{2}, 0)$;

Motor mechanical model schematic graph: $A_{14}(a, b)$, $C_{14}(e, 0)$, $D_{14}(0, 0)$;

Synchronous composite power angle graph: $A_{15}(h, i)$, $C_{15}(j, 0)$, $D_{15}(0, 0)$;

Motor end composite magnetic leakage graph: $T_{22}(0, 0)$, $X_{22}(X_1, Y_1)$, $Y_{22}(X_2, Y_2)$, $Z_{22}(X_3, Y_3)$;

Wherein, points A_{10}, A_{11} and A_{14} indicate the planar coordinates of the vector vertex of the synchronous motor magnetic excitation potential;

Points C_{10}, C_{11} and C_{14} indicate the planar coordinates of the vector vertex of the synchronous motor end voltage;

Points D_{10}, D_{11}, D_{12} and D_{14} indicate the planar coordinates of the vector vertex of the synchronous motor power angle;

Point A_{12} indicates the planar coordinates of the vector midpoint of the synchronous motor magnetic excitation potential;

Point C_{12} indicates the planar coordinates of the vector midpoint of the synchronous motor end voltage;

The distance between points A_{15} and D_{15} indicates the synchronous end voltage of the synchronous motor, and the distance between points C_{15} and D_{15} indicates the synchronous system voltage; and

T_{22}, X_{22}, Y_{22} and Z_{22} are the image coordinates of the motor end composite magnetic leakage graph;

(2) The gist of imaging

a) The coordinate points in each figure only integrate with the present figure and only image in the present figure, the image moves smoothly;

b) The axial center of the rigid body of the synchronous motor rotor: depicting circles by taking points D_{10}, D_{12}, D_{14} and D_{15} respectively as the center of the circle and taking 1/20 of the length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation as the radius; and the circles are in white;

c) The rigid body of the synchronous motor rotor: depicting

circles by taking points D_{10}, D_{12}, D_{14} and D_{15} respectively as the center of the circle and taking 1/5 of the length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation as the radius; the intersection portions of the rotor rigid body circles with the rotor rigid body axial center circles are still in white, and the rest portions are in dark blue;

d) The lever of the synchronous motor rotor: the lever is in dark blue (the same color as the rotor rigid body), and the line width of the lever is the same as the diameter of the axial center circle; the intersection portion of the lever with the rotor axial center is still in white;

Points D_{10} and A_{10}, points A_{12} and A_{13}, points A_{14} and D_{14} and points A_{15} and D_{15} are connected by levers respectively;

e) The stator rigid body: depicting a circle by taking point D_{12} as the center of the circle and taking the 1/3 length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation as the radius; the portion out of the intersection portion of this circle with the rotor rigid body circle, the rotor axial center circle and the rotor lever is in light grey;

Points C_{10} and D_{10}, points C_{14} and D_{14}, and points C_{15} and D_{15} are connected by thin real line respectively, and at both ends of the segments there are prolongations as long as 1/2 length of the segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation; the intersection portions with the rotor rigid body circle and the rotor axial center circle are represented by dotted lines; the part under the thin real line is shadowed with parallel thin-short bias, while the rotor rigid body circle and the rotor axial center circle are not shadowed;

f) The stator lever: the stator lever is connected between points C_{12} and C_{13} with the same width as that of the rotor lever and the same color as that of the stator rigid body, and its intersection portion with the rotor rigid body circle and the rotor axial center circle is still in the color of the rotor rigid body circle and the rotor axial center circle;

Points C_{10} and D_{10}, points C_{14} and D_{14}, and points C_{15} and D_{15} are connected by black bold lines representing levers, the width of the bold line is the radius of the axial center circle, and its intersection portion with the rotor axial center circle and the

rotor rigid body circle is represented by thin dotted line;

g) The spring: the spring is in black with realistic imaging; it is visualized to extend and shrink according to the lengthening and shortening of the spring; there ought to be an obvious joint between the spring and the lever;

Points A_{10} and C_{10}, points A_{12} and C_{12}, points A_{13} and C_{13}, and points A_{14} and C_{14} are connected with springs respectively;

h) The joint between the spring and the lever: the joint between the spring and the lever is represented by a white circle, the diameter of the circle is slightly shorter than the diameter of the lever, the circle is positioned at the axial centers of the lever and the spring, and its connection with the spring is obviously visualized; the distances from the center of the circle on top of the lever representing the joint to both sides of the lever equal to the distances from the center to the ends of the lever respectively;

i) The segments: points A_{10} and G_{10} and points C_{10} and G_{10} are connected by thin black lines respectively;

j) The vectors: linking points D_{11} and A_{11} by a segment with an arrow pointing to A_{11}; linking points D_{11} and C_{11} by a segment with an arrow pointing to C_{11}; linking points C_{11} and A_{11} by a segment with an arrow pointing to C_{11}; points T_{22} and X_{22} are linked by a black bold segment with an arrow pointing to X_{22}; points T_{22} and Y_{22} are linked by a black bold segment with an arrow pointing to Y_{22}; points T_{22} and Z_{22} are linked by a colorful bold segment with an arrow pointing to Z_{22}; points X_{22} and Z_{22} and points Y_{22} and Z_{22} are linked by black thin dotted segments respectively;

k) The marks of the coordinate points:

A_{10} for "E_0", point C_{10} for "U", point D_{10} for "O", and point G_{10} for "M";

Point A_{11} for "$\dot{E}_0$", point C_{11} for "$\dot{U}$", and point D_{11} for "O";

segment $A_{11}C_{11}$ for "$\dot{E}_a$";

Point A_{12} for "$\Sigma\dot{\Phi}_0$", point C_{12} for "$\Sigma\Sigma\dot{\Phi}$", and point D_{12} for "O";

Point A_{14} for "$\Sigma\dot{\Phi}_0$", point C_{14} for "$\Sigma\Sigma\dot{\Phi}$", and point D_{14} for "O";

Point A_{15} for "E_0", point C_{15} for "U", and point D_{15} for "O";

The marks of the magnetic leakage composite graph: points X_{22},

Y_{22} and Z_{22} for "$\Sigma\dot{\Phi}_{0\sigma}$", "$\Sigma\dot{\Phi}_{a\sigma}$" and "$\Sigma\dot{\Phi}_{D\sigma}$" respectively;

The marks move with the moving of the positions of the coordinate points, and the relative positions of the marks and corresponding coordinate points keep constant;

l) The power angle marks: the dotted line representing the power angle passes through the center of the rotor, superposing the axial center of the lever, and being not longer than 1/3 of the length of segment $C_{10}D_{10}$ obtained when the synchronous motor is under rating operation; it is marked as "δ" within the range of the power angle, the levers at both sides of the power angle are connected by an arc, the vertex of the arc varies as the positions of the levers vary, the radius of the arc is longer than the radius of the rotor rigid body circle, and the center of the arc superposes the stator axial center;

m) The magnetic excitation adjustment signal marks:

Two methods:

(a) In accordance with the abrupt change algorithm, depending on the length percentage by which ΔE_0 takes the present magnetic excitation potential, when ΔE_0 is greater than a given value it reveals the abrupt change of the magnetic excitation potential; when ΔE_0 is positive, the adjustment signals are arranged from the top of the magnetic excitation lever to the rotor axial center, and when ΔE_0 is negative, the adjustment signals are arranged from the rotor axial center along the reverse direction of the magnetic excitation potential;

(b) In accordance with the calculation results obtained by the adjustment algorithm, by the values of E_{01}, E_{02} ... E_{0n}, the adjustments are represented with different colors and arranged depending on the length percentages they take; the increment-adjustment signals are closely arranged from the top of the magnetic excitation lever to the rotor axial center in sequence, and the reduction-adjustment signals are linearly and closely arranged from the rotor axial center along the reverse direction of the magnetic excitation potential in sequence;

On a displaying screen the colors of the adjustment signals are marked;

n) The PQ curve mark: determining the curve between points

M_{10} and N_{10} according to the end heat-emitting limit of the synchronous motor and the greatest operation power angle of the synchronous motor that the system permits, determining the $N_{10}O_{10}$ curve according to the greatest active power that the synchronous motor permits, determining the $O_{10}P_{10}$ curve according to the greatest stator magnetic flux, the greatest stator current and the greatest stator potential that the synchronous motor permits, and determining the $P_{10}Q_{10}$ curve according to the greatest rotor magnetic flux, the greatest rotor current and the greatest rotor voltage that the synchronous motor permits; points M_{10} and Q_{10} are both on the line $D_{10}G_{10}$, and points G_{10} and Q_{10} are connected by a thin line; Curve $M_{10}N_{10}O_{10}P_{10}Q_{10}$ (exclusive of the linear segment $M_{10}Q_{10}$) is depicted by a bold real line, the color of which is determined according to the user's requirement;

o) The composite magnetic leakage alarm circle: depicting a circle by taking T_{22} as the center of the circle and taking the greatest magnetic leakage flux that the synchronous motor permits as the radius; this circle is the alarm circle, which is represented by a colorful bold curve;

p) The synchronous image requirements: depicting dotted circles by taking point D_{15} as the center of the circle and taking segments $D_{15}A_{15}$ and $D_{15}C_{15}$ as the radius respectively;

q) The mechanical model may rotate anticlockwise dynamically, the ratio of the rotation speed of the model and that of the real object is marked on the screen, and the rotation speed ratio may be selected;

r) The image alarm display: when an alarm is given on electric parameters or magnetic flux, the marks turn to red flickers, the speaker of the computer whistles, and the corresponding segments in the composite power angle graph and its sub-figures and the magnetic leakage graph turn to red flickers; and when the alarm is relieved, the alarm marks or segments stay red but without flicker;

s) In accordance with the afore-mentioned imaging requirements, the six graphs obtained through program process can be combined with each other according to the requirements of the user, and any one of the combined images can be further combined with the digital display image of Figure 11; adjustments may be

made within a small range on the stator radius and rotor radius, the axial center radius of the stator and of the rotor, the diameter of the lever and the spring joint radius of the synchronous motor, which are given in the composite power angle graph and its sub-figures; the mechanical model graphs may be made as various three-dimensional mechanical model graphs; and the color of the models may be adjusted according to the requirements of the user;

The computing program process including:

(1) Determination of the parameters

Given parameters: the leakage reactance X_σ of the motor stator, synchronous motor voltage, current and frequency conversion coefficients K_U, K_I and K_ω, system voltage and frequency conversion coefficients K_{XU} and $K_{X\omega}$, active and reactive power conversion coefficients K_P, K_Q and K_m, the conversion coefficients K_L, K_{GL} and K_{BL} of the magnetic excitation voltage and the operating excitation voltage and backup excitation voltage of the synchronous motor, the conversion coefficients K_f, K_{Gf} and K_{Bf} of the magnetic excitation current and the operating excitation current and backup excitation current of the synchronous motor, the computing coefficient m of the synchronous motor, negative sequence voltage conversion coefficient K_F, the synchronous conversion coefficients K_T and K_N of the synchronous motor end voltage, the synchronous conversion coefficients K_{XT} and K_{XN} of the system voltage, the conversion coefficient K_{TJ} of the voltage of the magnetic excitation adjustment signal, and magnetic flux leakage coefficients K_1 and K_2; allowable range of main parameters: main parameters comprise motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux, power angle and system voltage; rating parameters of the motor mainly comprise: motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power,

stator magnetic flux, rotor magnetic flux and system voltage;

(2) Calculation of the parameters

a) $P_j = K_P P$, $\Sigma P = K_m P_j$

b) $Q_j = K_Q Q$, $\Sigma Q = K_m Q_j$

c) $I_{aj} = K_I I_a$, $I_{bj} = K_I I_b$, $I_{cj} = K_I I_c$

d) $U_{abj} = K_U U_{ab}$, $U_{bcj} = K_U U_{bc}$, $U_{caj} = K_U U_{ca}$

e) $I_f = K_f i_L$, $I_{Gf} = K_{Gf} i_G$, $I_{Bf} = K_{Bf} i_{BY}$

f) $F = K_\omega f$, $F_X = K_{X\omega} f_X$

g) $U_{Fj} = K_F U_F$

h) $U_{xabj} = K_{XU} U_{xab}$, $U_{xbcj} = K_{XU} U_{xbc}$, $U_{xcaj} = K_{XU} U_{xca}$

i) $u_{Lj} = K_L u_L$, $u_{Gj} = K_{GL} u_G$, $u_{Bj} = K_{BL} u_B$

(3) The value of the direct-axis synchronous reactance X_d of the non-salient-pole synchronous motor

Two methods for determining the value of the direct-axis synchronous reactance X_d of the non-salient-pole synchronous motor are:

a) Directly determining the value of the direct-axis synchronous reactance X_d in accordance with the air gap potential E_δ obtained when the synchronous motor is under normal operation, and the value of X_d being kept constant;

b) Determining the value of X_d in accordance with the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d, and comprising the steps of:

(a) Depicting the dynamotor zero load ($I_a = 0$) curve and the zero power factor ($I_a = I_N$) curve, namely curve $U=f_0(I_f)$ and curve $U=f_N(I_f)$;

(b) Determining the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d;

In accordance with the curves $U=f_0(I_f)$ and $U=f_N(I_f)$, taking n magnetic excitation current values of I_{f1}, I_{f2} … I_{fn}, and determining on the curve $U=f_N(I_f)$ points B_1, B_2 … B_n corresponding

to I_{f1}, I_{f2} ... I_{fn} based on the zero power factor curve; constructing n congruent triangles through points B, B_1, B_2 ⋯ B_n respectively (wherein segment CD is vertical to the I-coordinate, and $CD = I_N * X_\sigma$), intersecting with the zero load characteristic curve of U= $f_0(I_f)$ at points C, C_1, C_2, ⋯ C_n respectively, connecting points O and C_1, and extending segment OC_1 to intersect with the line that passes through point B_1 and is parallel to the U-coordinate at point A_1; similarly, connecting points O and C_2, ⋯ connecting points O and C_n, and extending segment OC_2 ⋯ extending OC_n, and intersecting with the lines that pass through points B_2 ⋯ B_n respectively and are parallel to the U-coordinate at points A_2 ⋯ A_n respectively;

Therefore, the synchronous saturated reactance corresponding to $E_{\delta 1}$, $E_{\delta 2}$ ... $E_{\delta n}$ respectively are: $X_{d1} = \frac{A_1B_1}{I_N}$, $X_{d2} = \frac{A_2B_2}{I_N}$ ... $X_{dn} = \frac{A_nB_n}{I_N}$; depicting the relationship graph of the air gap potential and the reactance in accordance with the relationship between $E_{\delta 1}$, $E_{\delta 2}$ ... $E_{\delta n}$ and respective corresponding synchronous saturated reactance X_{d1}, X_{d2} ... X_{dn};

(c) Computing E_δ

Let $\dot{W} = P_j + jQ_j = W\angle\varphi$; $\dot{U}_a = \frac{U_{abj}}{\sqrt{3}} = e$;

Then $\dot{I}_{aj} = I_{aj}\angle(-\varphi)$,

$\dot{E}_\delta = e + j\dot{I}_{aj} * X_\sigma$; $E_\delta = |\dot{E}_\delta|$

(d) Substituting the value of E_δ into function $X_d = f(E_\delta)$ to obtain the value of X_d;

(4) Calculations

a) $a = e + \frac{Q_j}{me} X_d$

b) $b = \frac{P_j}{me} X_d$

c) Calculations of components of the magnetic excitation

Two calculation methods are:

(a) Abrupt change algorithm

Assuming the average magnetic excitation potential of

the synchronous motor during the period of ΔT from some certain time till now as ΣE_0, and the current magnetic excitation potential being E_0; assuming $\Delta E_0 = E_0 - \Sigma E_0$; the value of ΔT and the times of sampling the magnetic excitation potential may be set;

(b) Adjustment algorithm

Assuming the total automatic magnetic excitation adjustment of the integrated amplifier as ΣU; the components respectively are: $\Delta U = K_{TJ}U_1$, $U' = K_{TJ}U_2$, $\Delta f = K_{TJ}U_3$ $\cdots X = K_{TJ}U_n$; $\Sigma U = K_{TJ}(U_1+U_2+\cdots+U_n)$, $f_1 = \frac{K_{TJ}U_1}{\Sigma U}$, $f_2 = \frac{K_{TJ}U_2}{\Sigma U}$ ... $f_n = \frac{K_{TJ}U_n}{\Sigma U}$

Calculating $E_{01} = f_1\sqrt{a^2+b^2}$, $E_{02} = f_2\sqrt{a^2+b^2}$ ... $E_{0n} = f_n\sqrt{a^2+b^2}$

d) Calculation of the per-unit value of the magnetic flux: assuming when the frequency is at the rating value, the per-unit value of a certain magnetic flux of the synchronous motor equals to the per-unit value of the corresponding voltage; determining the per-unit values of the magnetic excitation flux and the stator total magnetic flux of the motor according to the relationship among frequency, voltage and magnetic flux; comparing the calculated values with the given values, and alarming when the calculated values are larger than the given values;

e) comparing various electric parameters with respective given values, and alarming when the electric parameters are larger than the given values;

f) Calculation of the coordinates of the magnetic flux leakage

$X_1=K_1a$; $Y_1=K_1b$; $X_2=K_2(e-a)$; $Y_2=-K_2b$; $X_3=X_1+X_2$; $Y_3=Y_1+Y_2$

(5) During the synchronous parallel-network or parallel-off, namely when $I_a = I_b = I_c = 0$, performing the following calculations on the synchronous motor voltage signal and the system voltage signal inputted to the computer:

(a) $\dot{U} = K_T(u_{AB} + u_{BC}\angle 120^\circ + u_{CA}\angle 240^\circ) = U\angle\alpha$

(b) $\dot{U}_x = K_{XT}(u_{XAB} + u_{XBC}\angle 120^\circ + u_{XCA}\angle 240^\circ) = U_x\angle\varepsilon$

(c) $\frac{\dot{U}}{\dot{U}_x} = \frac{U}{U_x}\angle\delta_x$

(d) $\overline{\delta}_x = \frac{\delta_1+\delta_2+\cdots\delta_n}{n}$ (wherein $\delta_1\delta_2\cdots\delta_n$ are the values of the

first, the second ··· and the n^{th} δ_x measured within a certain time period; when a second measured value enters, the value of the first δ_1 is abandoned, and when the next measured value enters, the value of the second δ_2 is abandoned; analogically, the new measured values replace the old ones; and the time period and the value of n can be set.)

(e) $h = K_N U_{abj} * \cos\bar{\delta}_x$

(f) $i = K_N U_{abj} * \sin\bar{\delta}_x$

(g) $j = K_{XN} U_{xabj}$

(6) Comparing various electric parameters with respective given values, and alarming when the electric parameters are out of the prescribed ranges.

4. The method for measuring the operating state of synchronous motor by using composite power angle meter according to Claim 2, wherein the displaying program process and computing program process comprise the following steps for a salient-pole synchronous motor:

The displaying program process including:

(1) Establishing image coordinates of composite power angle graph, electric power angle vector graph, motor mechanical model graph, motor mechanical model schematic graph, synchronous composite power angle graph and motor end composite magnetic leakage graph of the salient-pole synchronous motor:

Composite power angle graph: $A_0(a, b)$, $B_0(c, d)$, $C_0(e, 0)$, $D_0(0, 0)$, $E_0(f, g)$, $F_0(f, 0)$, $G_0(c, 0)$;

Electric power angle vector graph: $A_1(a, b)$, $C_1(e, 0)$, $D_1(0, 0)$, $E_1(f, g)$;

Motor mechanical model graph: $A_2(\frac{a}{2}, \frac{b}{2})$, $B_2(\frac{c}{2}, \frac{d}{2})$, $C_2(\frac{e}{2}, 0)$, $D_2(0, 0)$, $E_2(\frac{f}{2}, \frac{g}{2})$, $A_3(-\frac{a}{2}, -\frac{b}{2})$, $B_3(-\frac{c}{2}, -\frac{d}{2})$, $C_3(-\frac{e}{2}, 0)$, $E_3(-\frac{f}{2}, -\frac{g}{2})$;

Motor mechanical model schematic graph: $A_4(a, b)$, $B_4(c, d)$, $C_4(e, 0)$, $D_4(0, 0)$, $E_4(f, g)$;

Synchronous composite power angle graph: $A_5(h, i)$, $C_5(j, 0)$, $D_5(0, 0)$;

Motor end composite magnetic leakage graph: $T_{20}(0, 0)$, $X_{20}(X_1, Y_1)$,

$Y_{20}(X_2, Y_2)$, $Z_{20}(X_3, Y_3)$;

Wherein, points A_0, A_1 and A_4 indicate the planar coordinates of the vector vertex of the synchronous motor magnetic excitation potential; points C_0, C_1 and C_4 indicate the planar coordinates of the vector vertex of the synchronous motor end voltage; points D_0, D_1, D_2 and D_4 indicate the planar coordinates of the vector vertex of the synchronous motor power angle; point A_2 indicates the planar coordinates of the vector midpoint of the synchronous motor magnetic excitation potential; point C_2 indicates the planar coordinates of the vector midpoint of the synchronous motor end voltage; the distance between A_5 and D_5 indicates the synchronous end voltage of the synchronous motor, the distance between C_5 and D_5 indicates the synchronous system voltage; and T_{20}, X_{20}, Y_{20} and Z_{20} are the image coordinates of the motor end composite magnetic leakage graph;

(2) The gist of imaging

a) The coordinate points in each figure only integrate with the present figure and only image in the present figure, the image moves smoothly;

b) The axial center of the rigid body of the synchronous motor rotor: depicting circles by taking points D_0, D_2, D_4 and D_5 respectively as the center of the circle and taking 1/20 of the length of the segment C_0D_0 obtained when the synchronous motor is under rating operation as the radius;

c) The rigid body of the synchronous motor rotor: depicting circles by taking points D_0, D_2, D_4 and D_5 respectively as the center of the circle and taking 1/4 of the length of the segment C_0D_0 obtained when the synchronous motor is under rating operation as the radius;

d) The lever of the synchronous motor rotor: the lever is in dark blue (the same color as the rotor rigid body), and the line width of the lever is the same as the diameter of the axial center circle; when the rotor lever is a T-shaped lever, the length of the top beam of the T-shaped lever in each of the composite power angle graph, motor mechanical model schematic graph and synchronous composite power angle graph is two times as much as the length of the segment D_0C_0 obtained when the synchronous motor is under rating operation, and the top beam is central-positioned; the length of

the top beam of the T-shaped lever in the motor mechanical model graph is two times as much as the length of the segment D_2C_2 obtained when the synchronous motor is under rating operation, and the top beam is central-positioned;

Points D_0 and A_0, points A_3 and A_2, points D_4 and A_4 and points D_5 and A_5 are connected by levers respectively;

e) The stator rigid body: depicting a circle by taking point D_2 as the center of the circle and taking the 1/3 length of the segment C_0D_0 obtained when the synchronous motor is under rating operation as the radius;

Points C_0 and D_0, points C_4 and D_4, and points C_5 and D_5 are connected by thin real line respectively, and at both ends of the segments there are prolongations as long as 1/2 length of the segment C_0D_0 obtained when the synchronous motor is under rating operation; the intersection portions with the rotor rigid body circle and the rotor axial center circle are represented by dotted lines; the part under the thin real line is shadowed with parallel thin-short bias, while the rotor rigid body circle and the rotor axial center circle are not shadowed;

f) The stator lever: the stator lever is connected between points C_2 and C_3 with the same width as that of the rotor lever; points C_0 and D_0, points C_4 and D_4, and points C_5 and D_5 are connected by black bold lines representing levers, the width of the bold line is the radius of the axial center circle, and its intersection portion with the rotor axial center circle and the rotor rigid body circle is represented by thin dotted line;

g) The spring: the spring is in black with realistic imaging; it is visualized to extend and shrink according to the lengthening and shortening of the spring; there ought to be an obvious joint between the spring and the lever;

Points B_0 and C_0, points E_0 and C_0, points B_2 and C_2, points E_2 and C_2, points B_3 and C_3, points E_3 and C_3, points B_4 and C_4, and points E_4 and C_4 are connected with springs respectively;

h) The joint between the spring and the lever: the joint between the spring and the lever is represented by a white circle, the diameter of the circle is slightly shorter than the diameter of the lever, the circle is positioned at the axial centers of the lever and the spring, and its connection with the spring is

obviously visualized; the distances from the center of the circle on top of the lever representing the joint to both sides of the lever equal to the distances from the center to the ends of the lever;

i) The segments: points E_0 and F_0, points B_0 and G_0, and points C_0 and G_0 are connected by thin black lines respectively;

j) The vectors: linking points D_1 and A_1 by a segment with an arrow pointing to A_1; linking points E_1 and A_1 by a segment with an arrow pointing to A_1; linking points C_1 and E_1 by a segment with an arrow pointing to E_1; linking points D_1 and C_1 by a segment with an arrow pointing to C_1; segment E_1A_1 is under segment D_1A_1; points T_{20} and X_{20} are linked by a black bold segment with an arrow pointing to X_{20}; points T_{20} and Y_{20} are linked by a black bold segment with an arrow pointing to Y_{20}; points T_{20} and Z_{20} are linked by a colorful bold segment with an arrow pointing to Z_{20}; points X_{20} and Z_{20} and points Y_{20} and Z_{20} are linked by black thin dotted segments respectively;

k) The marks of the coordinate points:

Point A_0 for "E_0", point B_0 for "E_d", point C_0 for "U", point D_0 for "O", point E_0 for "E_q", point F_0 for "M", and point G_0 for "N";

Point A_1 upper for "$\dot{E}_0$", lower for "$\dot{E}_d$", point C_1 for "$\dot{U}$", point D_1 for "O", and point E_1 for "$\dot{E}_q$";

Point A_2 for "$\Sigma\dot{\Phi}_0$", point B_2 for "$\Sigma\dot{\Phi}_d$", point C_2 for "$\Sigma\Sigma\dot{\Phi}$", point D_2 for "O", and point E_2 for "$\Sigma\dot{\Phi}_q$";

Point A_4 for "$\Sigma\dot{\Phi}_0$", point B_4 for "$\Sigma\dot{\Phi}_d$", point C_4 for "$\Sigma\Sigma\dot{\Phi}$", point D_4 for "O", and point E_4 for "$\Sigma\dot{\Phi}_q$";

Point A_5 for "E_0", point C_5 for "U", and point D_5 for "O"; and

Points X_{20}, Y_{20} and Z_{20} for "$\Sigma\dot{\Phi}_{0\sigma}$", "$\Sigma\dot{\Phi}_{a\sigma}$" and "$\Sigma\dot{\Phi}_{D\sigma}$" respectively;

The marks move with the moving of the positions of the coordinate points, and the relative positions of the marks and corresponding coordinate points keep constant;

l) The power angle marks: the dotted line representing the power angle passes through the center of the rotor, superposing the

axial center of the lever, and being not longer than 1/3 of the length of segment C_0D_0 obtained when the synchronous motor is under rating operation; it is marked as "δ" within the range of the power angle, the levers at both sides of the power angle are connected by an arc, the vertex of the arc varies as the positions of the levers vary, the radius of the arc is longer than the radius of the rotor rigid body circle, and the center of the arc superposes the stator axial center;

m) The magnetic excitation adjustment signal marks:

Two methods:

(a) In accordance with the abrupt change algorithm, depending on the length percentage by which ΔE_0 takes the present magnetic excitation potential, when ΔE_0 is greater than a given value it reveals the abrupt change of the magnetic excitation potential; when ΔE_0 is positive, the adjustment signals are arranged from the top of the magnetic excitation lever to the rotor axial center, and when ΔE_0 is negative, the adjustment signals are arranged from the rotor axial center along the reverse direction of the magnetic excitation potential; on the displaying screen the adjustment signals and their colors are marked;

(b) In accordance with the adjustment algorithm and the calculation results of the computer, by the values of E_{01}, E_{02} ... E_{0n}, the adjustments are represented with different colors and arranged depending on the length percentages they take; the increment-adjustment signals are closely arranged from the top of the magnetic excitation lever to the rotor axial center in sequence, and the reduction-adjustment signals are linearly and closely arranged from the rotor axial center along the reverse direction of the magnetic excitation potential in sequence; on the displaying screen the adjustment signals and their colors are marked;

n) The PQ curve mark: determining the curve between points M_0 and N_0 according to the end heat-emitting limit of the synchronous motor and the greatest operation power angle of the synchronous motor that the system permits, determining the N_0O_0 curve according to the greatest active power that the synchronous motor permits, determining the O_0P_0 curve according to the greatest stator magnetic flux, the greatest stator current and the greatest stator potential

that the synchronous motor permits, and determining the P_0Q_0 curve according to the greatest rotor magnetic flux, the greatest rotor current and the greatest rotor voltage that the synchronous motor permits; points M_0 and Q_0 are both on the line D_0G_0, and points G_0 and Q_0 are connected by a thin line; curve $M_0N_0O_0P_0Q_0$ (exclusive of the linear segment M_0Q_0) is depicted by a bold real line, the color of which is determined according to the user's requirement;

o) The composite magnetic leakage alarm circle: depicting a circle by taking T_{20} as the center of the circle and taking the greatest magnetic leakage flux that the synchronous motor permits as the radius; this circle is the alarm circle, which is represented by a colorful bold curve;

p) The synchronous image requirements: depicting dotted circles by taking point D_5 as the center of the circle and taking segments D_5A_5 and D_5C_5 as the radius respectively;

q) The mechanical model may rotate anticlockwise dynamically, the ratio of the rotation speed of the model and that of the real object is marked on the screen, and the rotation speed ratio may be selected;

r) The image alarm display: when an alarm is given on electric parameters or magnetic flux, the marks turn to red flickers, the speaker of the computer whistles, and the corresponding segments in the composite power angle graph and its sub-figures and the end composite magnetic leakage graph turn to red flickers; and when the alarm is relieved, the alarm marks or segments stay red but without flicker;

s) In accordance with the afore-mentioned imaging requirements, the six graphs obtained through program process can be combined with each other according to the requirements of the user, and any one of the combined images can be further combined with the digital display image of Figure 11; adjustments may be made within a small range on the stator radius and rotor radius, the axial center radius of the stator and of the rotor, the diameter of the lever and the spring joint radius of the synchronous motor, which are given in the composite power angle graph and its sub-figures; the mechanical model graphs may be made as various three-dimensional mechanical model graphs; and the color of the models may be adjusted according to the requirements of the

user;

The computing program process including:

(1) Determination of the parameters

Given parameters: the leakage reactance X_σ of the motor stator (Potier reactance), quadrature-axis synchronous reactance X_q, synchronous motor voltage, current and frequency conversion coefficients K_U, K_I and K_ω, system voltage and frequency conversion coefficients K_{XU} and $K_{X\omega}$, active and reactive power conversion coefficients K_P, K_Q and K_m, the conversion coefficients K_L, K_{GL} and K_{BL} of the magnetic excitation voltage and the operating excitation voltage and backup excitation voltage of the synchronous motor, the conversion coefficients K_f, K_{Gf} and K_{Bf} of the magnetic excitation current and the operating excitation current and backup excitation current of the synchronous motor, negative sequence voltage conversion coefficient K_F, the synchronous conversion coefficients K_T and K_N of the synchronous motor end voltage, the synchronous conversion coefficients K_{XT} and K_{XN} of the system voltage, the conversion coefficient K_{TJ} of the voltage of the magnetic excitation adjustment signal, and magnetic flux leakage coefficients K_1, K_2 and K_3; allowable range of main parameters: main parameters comprise motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux, power angle and system voltage; rating parameters of the motor mainly comprise: motor end voltage, stator current, magnetic excitation voltage, magnetic excitation current, active power, reactive power, stator magnetic flux, rotor magnetic flux and system voltage;

(2) Calculation of the parameters

a) $P_j = K_P P$, $\Sigma P = K_m P_j$

b) $Q_j = K_Q Q$, $\Sigma Q = K_m Q_j$

c) $I_{aj} = K_I I_a$, $I_{bj} = K_I I_b$, $I_{cj} = K_I I_c$

d) $U_{abj} = K_U U_{ab}$, $U_{bcj} = K_U U_{bc}$, $U_{caj} = K_U U_{ca}$

e) $I_f = K_f i_L$, $I_{Gf} = K_{Gf} i_G$, $I_{Bf} = K_{Bf} i_{BY}$

f) $F = K_\omega f$, $F_X = K_{X\omega} f_X$

g) $U_{Fj} = K_F U_F$

h) $U_{xabj} = K_{XU} U_{xab}$, $U_{xbcj} = K_{XU} U_{xbc}$, $U_{xcaj} = K_{XU} U_{xca}$

i) $u_{Lj} = K_L u_L$, $u_{Gj} = K_{GL} u_G$, $u_{Bj} = K_{BL} u_B$

(3) Determination of the value of the direct-axis synchronous reactance X_d of the salient-pole synchronous motor

Two methods for determining the value of the direct-axis synchronous reactance X_d of the salient-pole synchronous motor are:

a) Directly determining the value of the direct-axis synchronous reactance X_d in accordance with the air gap potential E_δ obtained when the synchronous motor is under normal operation, and the value of X_d being kept constant;

b) Determining the value of X_d through the value of E_δ in accordance with the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d, and comprising the steps of:

(a) Depicting the dynamotor zero load ($I_a = 0$) curve and the zero power factor ($I_a = I_N$) curve, namely curve $U=f_0(I_f)$ and curve $U=f_N(I_f)$;

(b) Determining the function relationship between the air gap potential E_δ of the synchronous motor and the direct-axis synchronous reactance X_d;

In accordance with the curves $U=f_0(I_f)$ and $U=f_N(I_f)$, taking n magnetic excitation current values of I_{f1}, I_{f2} ... I_{fn}, and determining on the curve $U=f_N(I_f)$ points B_1, B_2 ⋯ B_n corresponding to I_{f1}, I_{f2} ... I_{fn} based on the zero power factor curve; Constructing n congruent triangles through points B, B_1, B_2 ⋯ B_n respectively (wherein segment CD is vertical to the I-coordinate, and $CD = I_N * X_\sigma$), intersecting with the zero load characteristic curve of $U= f_0(I_f)$ at points C, C_1, C_2, ⋯ C_n respectively, connecting points O and C_1, and extending segment OC_1 to intersect with the

line that passes through point B_1 and is parallel to the U-coordinate at point A_1; similarly, connecting points O and C_2, ··· connecting points O and C_n, and extending segment OC_2 ··· extending OC_n, and intersecting with the lines that pass through points B_2 ··· B_n respectively and are parallel to the U-coordinate at points A_2 ··· A_n respectively;

Therefore, the synchronous saturated reactance corresponding to $E_{\delta 1}$, $E_{\delta 2}$ ... $E_{\delta n}$ respectively are: $X_{d1} = \frac{A_1B_1}{I_N}$, $X_{d2} = \frac{A_2B_2}{I_N}$ ... $X_{dn} = \frac{A_nB_n}{I_N}$; Depicting the relationship graph of the air gap potential and the reactance in accordance with the relationship between $E_{\delta 1}$, $E_{\delta 2}$ ... $E_{\delta n}$ and respective corresponding synchronous saturated reactance X_{d1}, X_{d2} ... X_{dn};

(c) Computing E_δ;

Let $\dot{W} = P_j + jQ_j = W\angle\varphi$; $\dot{U}_a = \frac{U_{aby}}{\sqrt{3}} = e$;

Then $\dot{I}_{aj} = I_{aj}\angle(-\varphi)$,

$\dot{E}_\delta = e + j\dot{I}_{aj} * X_\sigma$; $E_\delta = |\dot{E}_\delta|$

(d) Substituting the value of E_δ into function $X_d = f(E_\delta)$ to obtain the value of X_d;

(4) Calculations

a) $\dot{H} = e + j\dot{I}_{aj} * X_q = H\angle\delta$ $\quad \delta(90^\circ\rangle\delta\rangle - 90^\circ)$ can be determined by this equation

b) $I_d = I_{aj}\sin(\delta + \varphi)$

c) $I_q = I_{aj}\cos(\delta + \varphi)$

d) $a = (e * \cos\delta + I_d * X_d) * \cos\delta$

e) $b = (e * \cos\delta + I_d * X_d) * \sin\delta$

f) $c = e + I_d * X_d * \cos\delta$

g) $d = I_d * X_d * \sin\delta$

h) $f = e * \cos^2\delta$

i) $g = \frac{1}{2}e * \sin 2\delta$

j) Calculations of components of the magnetic excitation

Two calculation methods are:

(a) Abrupt change algorithm

Assuming the average magnetic excitation potential of the synchronous motor during the period of ΔT from some certain time till now as ΣE_0, and the current magnetic excitation potential being E_0; assuming $\Delta E_0 = E_0 - \Sigma E_0$; The value of ΔT and the times of sampling the magnetic excitation potential may be set;

(b) Adjustment algorithm

Assuming the total automatic magnetic excitation adjustment of the integrated amplifier as ΣU; the components respectively are: $\Delta U = K_{TJ} U_1$, $U' = K_{TJ} U_2$, $\Delta f = K_{TJ} U_3$ $\cdots X = K_{TJ} U_n$; $\Sigma U = K_{TJ}(U_1 + U_2 + \cdots + U_n)$, $f_1 = \frac{K_{TJ} U_1}{\Sigma U}$, $f_2 = \frac{K_{TJ} U_2}{\Sigma U}$ ... $f_n = \frac{K_{TJ} U_n}{\Sigma U}$

Calculating $E_{01} = f_1 \sqrt{a^2 + b^2}$, $E_{02} = f_2 \sqrt{a^2 + b^2}$ ... $E_{0n} = f_n \sqrt{a^2 + b^2}$

k) Calculation of coordinates of the magnetic flux leakage

$X_1 = K_1 a$; $Y_1 = K_1 b$; $X_2 = K_2(f-a) + K_3(c-a)$; $Y_2 = K_2(g-b) + K_3(d-b)$; $X_3 = X_1 + X_2$; $Y_3 = Y_1 + Y_2$

l) Calculation of the per-unit value of the magnetic flux: assuming when the frequency is at the rating value, the per-unit value of a certain magnetic flux of the synchronous motor equals to the per-unit value of the corresponding voltage; determining the per-unit values of the magnetic excitation flux and the stator total magnetic flux of the motor according to the relationship among frequency, voltage and magnetic flux, and displaying the per-unit values with digitals; comparing the calculated values with the given values, and alarming when the calculated values are larger than the given values;

m) Calculations of the per-unit values of various parameters according to the requirements;

(5) During the synchronous parallel-network or parallel-off, namely when $I_a = I_b = I_c = 0$, performing the following calculations on each set of the synchronous motor voltage and the system voltage inputted to the computer:

(a) $\dot{U} = K_T (u_{AB} + u_{BC} \angle 120^\circ + u_{CA} \angle 240^\circ) = U \angle \alpha$

(b) $\dot{U}_x = K_{XT} (u_{XAB} + u_{XBC} \angle 120^\circ + u_{XCA} \angle 240^\circ) = U_x \angle \varepsilon$

(c) $\frac{\dot{U}}{\dot{U}_x} = \frac{U}{U_x} \angle \delta_x$

(d) $\overline{\delta}_x = \frac{\delta_1 + \delta_2 + \cdots \delta_n}{n}$ (wherein $\delta_1 \delta_2 \cdots \delta_n$ are the values of the first, the second ⋯ and the n^{th} δ_x measured within a certain time period; when a second measured value enters, the value of the first δ_1 is abandoned, and when the next measured value enters, the value of the second δ_2 is abandoned; analogically, the new measured values replace the old ones; and the time period and the value of n can be set.)

(e) $h = K_N U_{abj} * \cos \overline{\delta}_x$

(f) $i = K_N U_{abj} * \sin \overline{\delta}_x$

(g) $j = K_{XN} U_{xabj}$

(6) Comparing various electric parameters with respective given values, and alarming when the electric parameters are out of the prescribed ranges.